

# CLOCK COMPARISON USING DIGITAL TELEVISION SIGNALS

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## Abstract

*The U.S. Naval Research Laboratory (NRL) and the U.S. Naval Observatory (USNO) have done precision clock comparison using an analog television signal as a common phase reference since the mid 1980s. With the demise of analog television in the United States, that method is no longer viable. A new technique has been developed using the pilot tone on the digital television signal. The system is currently running between NRL and USNO. This paper will present the design and show the performance achieved.*

# INTRODUCTION

Prior to the widespread availability of Global Positioning System (GPS) time transfer, television signals were used for time transfer. This was done either using a local television station's signal or, for wider coverage, a satellite television signal. In the Washington DC area, line 10 [1] of the WTTG (Channel 5) signal was used. The line method required the station to use a very stable clock to create its signal structure. As television signal generation hardware evolved, the capability to control the necessary parts of the signal was no longer present. At about the same time, GPS time transfer was becoming available. Initially, the GPS time transfer accuracy was in the 100s of nanoseconds, which was much better than what had been achieved with line10, but not as good as an RF carrier-based system [2].

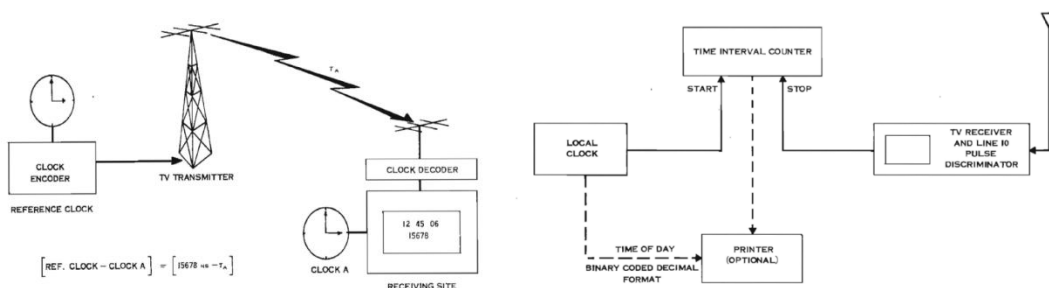


Figure 1. Line 10 TV time transfer system.

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In order to maintain a high-resolution link between NRL and USNO, the line 10 system as shown in Figure 1 was used initially for comparisons between the two groups. That system was replaced with an RF carrier-based concept, Figure 2, similar to the French concept [3]. The system also had the advantage of being independent of GPS. NRL built a synthesizer, which was installed in the WTTG transmitter. That allowed the RF carrier at 77.240 MHz to be referenced to a cesium clock. The broadcast television RF carrier phase was simultaneously measured at NRL and USNO by mixing the incoming carrier with a synthesized tone 2250 Hz above the TV carrier. The resulting audio tone had the relative phase between each laboratory and the clock at WTTG. One cycle at 2250 Hz then represented 1 cycle at the original carrier phase, or about 13 nanoseconds. The tone measured at USNO was sent to NRL via a standard analog telephone line. At NRL, the incoming 2250 Hz signal from USNO was compared with the local NRL 2250 Hz signal. The result of subtracting the two signals was the relative phase between USNO and NRL, Figures 3 and 4. That system provided relative time transfer with a noise level of less than 50 picoseconds, comparable to results currently being achieved with GPS carrier phase [2].

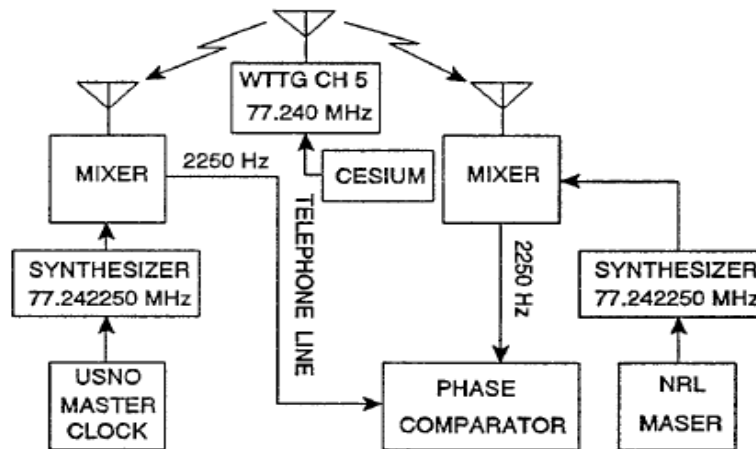


Figure 2. Implementation of analog TV time transfer at NRL and USNO.

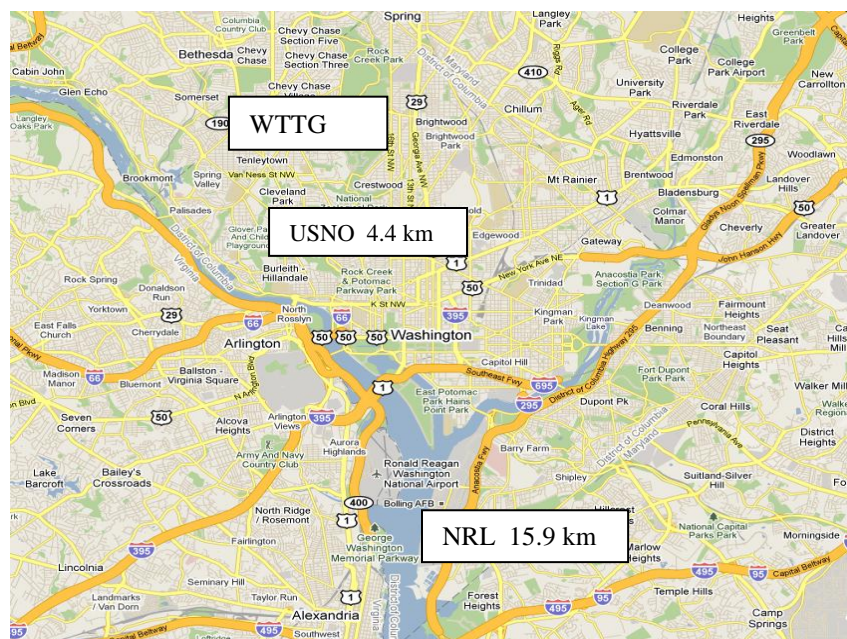


Figure 3. Locations of the participating sites.

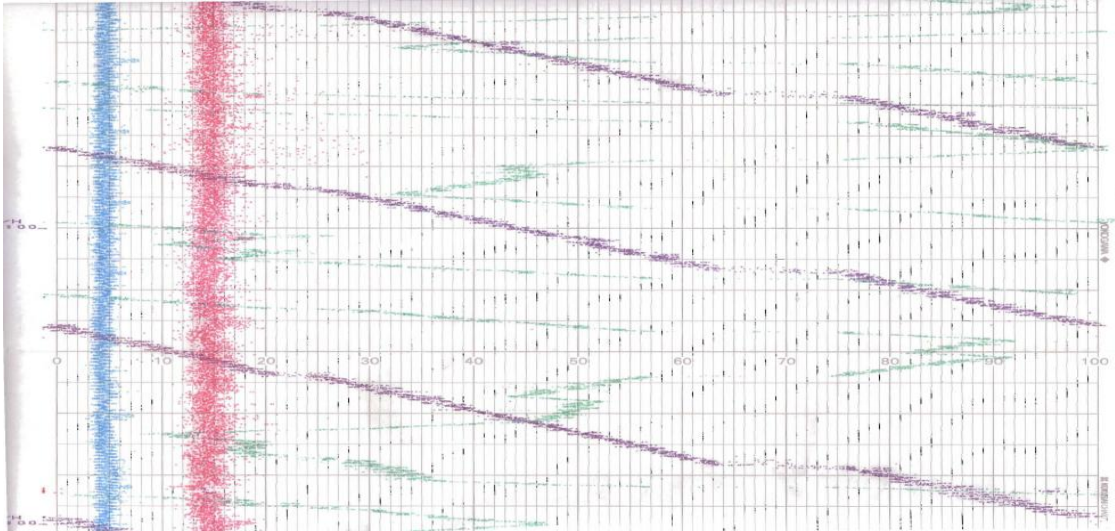


Figure 4. Analog time transfer output. The red and blue traces are the received signal levels at NRL. The violet line is the relative phase between the two. The green trace is the phase difference between the WTTG clock and NRL.

## SYSTEM UPDATES

With the advent of digital television (DTV), the analog RF carrier used as a common phase reference, the spectrum of which is shown in Figure 5, is no longer available. The new digital signal format does not have an equivalent signal with very strong signal-to-noise. The digital signal format, as shown in Figure 6, does have a pilot tone that is used by the television receiver to acquire the DTV signal.

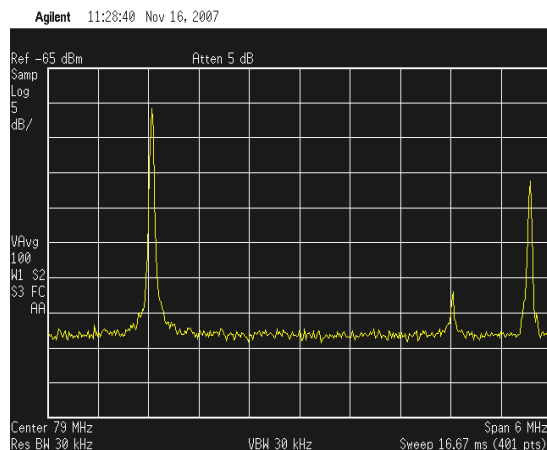


Figure 5. Analog TV spectrum.

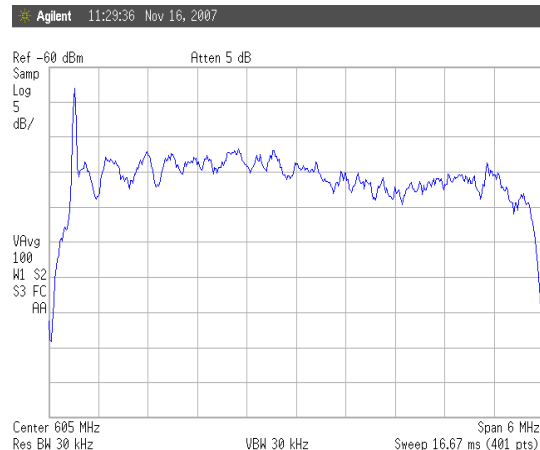


Figure 6. Digital TV spectrum.

However, due to the low signal-to-noise of the DTV pilot tone, the receiver for DTV became considerably more complex than the analog unit. While the original system used an RF carrier frequency of 77.240

MHz, the DTV signal is broadcast at approximately 602 MHz. Converting directly to audio at 2250 Hz was no longer a practical option, since the noise on the higher frequency would easily result in noise exceeding one cycle. Instead, the incoming signal is converted to 10 MHz and phase-locked to a crystal oscillator. This approach provides a very narrow effective bandwidth and is less sensitive to the noise on the pilot tone. Another complication was that the pilot tone is at an odd frequency, 602,309,440.53 Hz. That led to the use of a 48-bit Numerically Controlled Oscillator (NCO) as the local oscillator in the receiver. The design is shown in block diagram form in Figure 7 below.

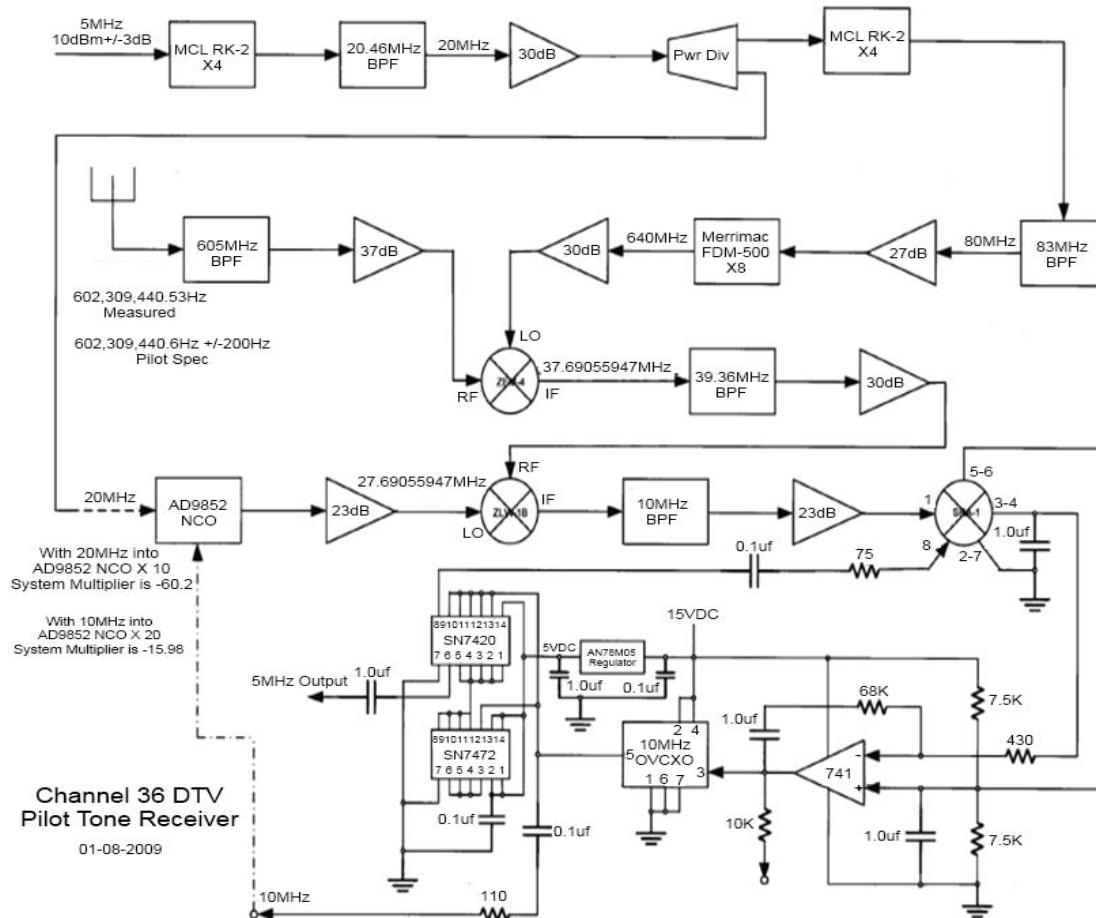


Figure 7. DTV receiver block diagram.

## DATA PROCESSING

The DTV receiver data at both USNO and NRL are measured using dual-mixer measurement systems and saved into data collection computers. The USNO data are then pulled daily from a FTP server to the data collection computer at NRL. A program then processes the USNO and NRL data files daily. The resulting phase difference between the references at the two sites is determined by:

$$\frac{d(\text{NRL})-d(\text{USNO})}{26.2}$$

The constant, 26.2, is the effective down-conversion ratio of frequency of the incoming signal to crystal oscillator frequency. The data are aligned by comparing the timestamps of the readings with a 1-second difference window.

All data are saved on a local server using common ASCII text files and can be viewed or further analyzed by either commercial software or custom in-house-built software. The data are saved in 20 second, 5 minute, and 1 hour daily files to help with plotting either short or long periods of data.

## RESULTS AND ANALYSIS

Figure 8 shows the phase residuals of NRL and USNO raw (unprocessed) DTV data. Notice the correlation in the two curves.

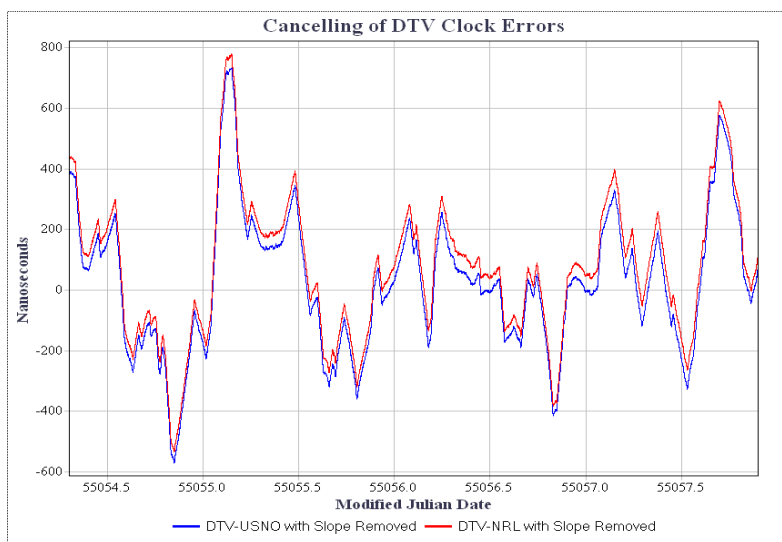


Figure 8. Phase residuals of raw DTV data.

Figure 9 shows the correlation between the phase residuals of raw DTV data and relative humidity at USNO. The daily variation in humidity is suspected to be the cause of the very large daily cycle (greater than one microsecond) in the raw data. The prior single site testing showed that temperature may also play a role.

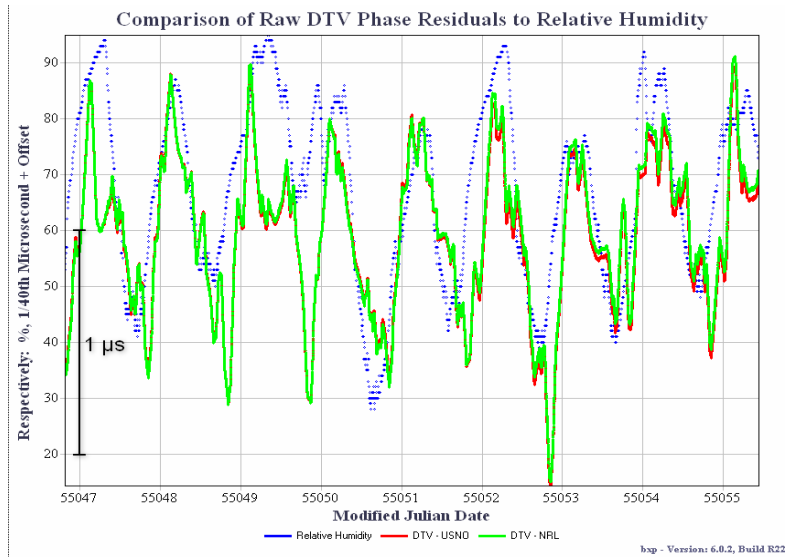


Figure 9. Raw DTV residuals compared with relative humidity.

Figure 10 shows the phase difference of the raw data between the two sites from the individual data shown above. The slope of  $5.9 \times 10^{-13}$  determined from these data corresponds to the nominal frequency offset of the hydrogen maser driving the NRL receiver with respect to USNO.

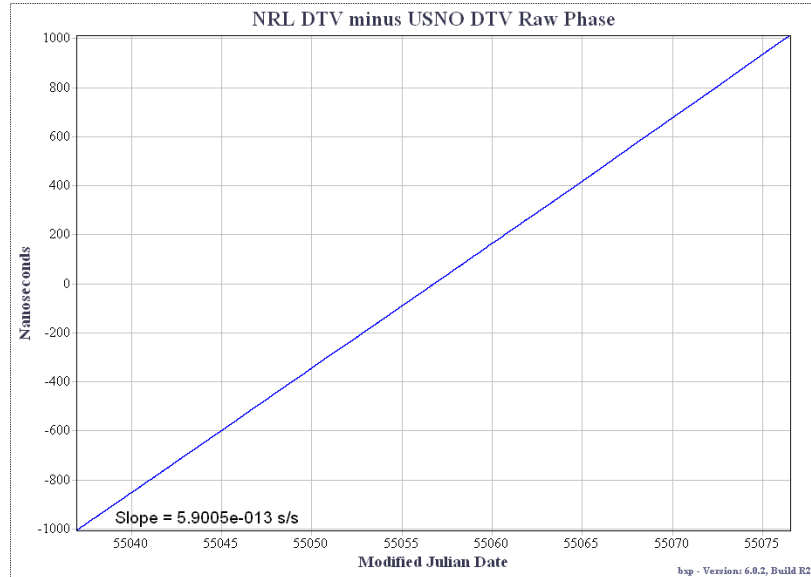


Figure 10. Differenced DTV data.

Most of the diurnal effects shown in the single site data, Figures 7 and 8, are removed by the differencing process. However, some structure remains in these data, as can be seen in Figure 11, which shows the result of a linear fit to the data. This structure has yet to be fully explained.

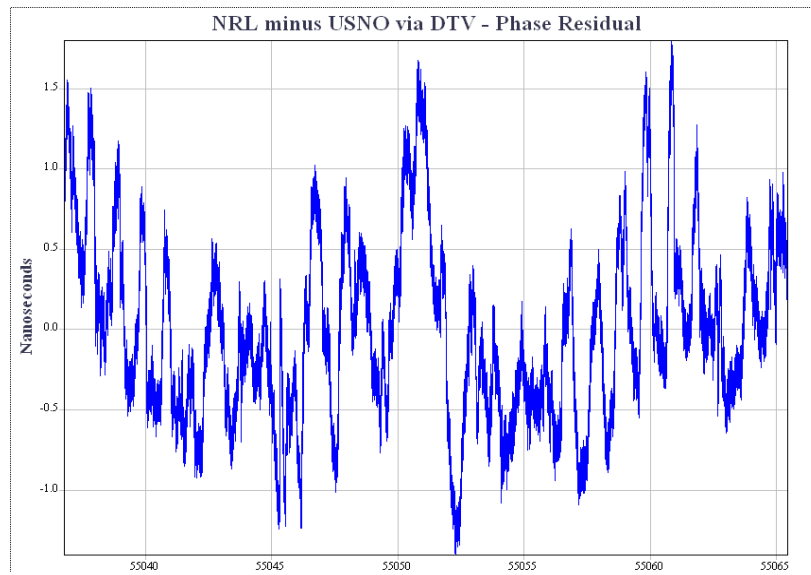


Figure 11. Linear residuals of differenced DTV data.

Figure 12 shows the Allan deviation of the data in Figure 11. At 1 day, the stability is around 1 nanosecond.

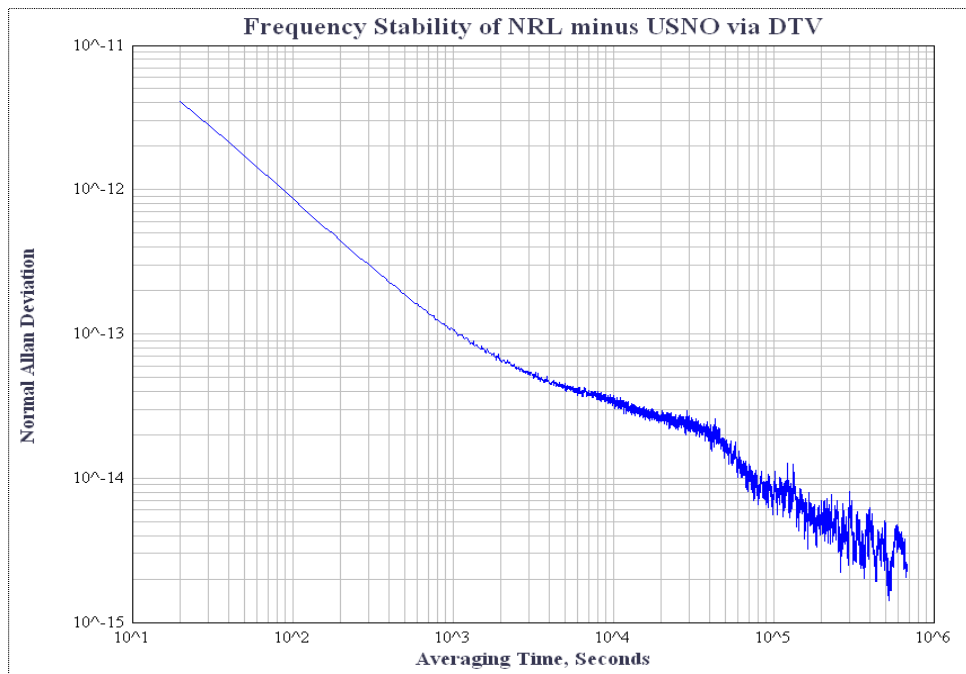


Figure 12. Stability of the phase residuals of the processed DTV data.



## CONCLUSIONS

A new method for relative time transfer using digital television signals has been demonstrated. Sub-nanosecond performance is obtainable. However, systematic effects are still present in the equipment used. Further analysis of these effects and application of techniques to compensate for them should make it possible to reduce the measurement noise levels to 10s of picoseconds. Further work is being done in this area.

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